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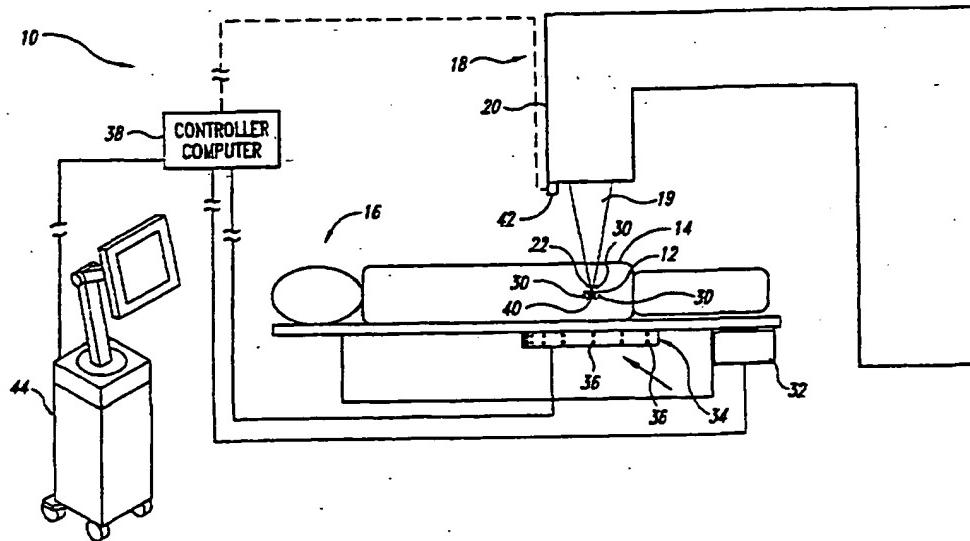
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(54) Title: GUIDED RADIATION THERAPY SYSTEM



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(57) Abstract: A system and method for accurately locating and tracking the position of a target, such as a tumor or the like, within a body. In one embodiment, the system includes one or more excitable beacons positionable in or near the target, an external excitation source that remotely excites the beacons to produce an identifiable signal, and a plurality of sensors spaced apart in a known geometry relative to each other. A computer is coupled to the sensors and configured to use the beacon measurements to identify a target isocenter within the target. The computer compares the position of the target isocenter with the location of the machine isocenter. The computer also controls movement of the patient and a patient support device so the target isocenter is coincident with the machine isocenter before and during radiation therapy.

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## GUIDED RADIATION THERAPY SYSTEM

## TECHNICAL FIELD

This invention relates generally to radiation therapy systems, and more particularly to systems and methods for accurately locating and tracking a target in a body to which guided radiation therapy is delivered.

## BACKGROUND OF THE INVENTION

Recent advances in radiation therapy are providing new avenues of effective treatment for localized cancer. These include three-dimensional conformal external beam radiation, intensity modulated radiation therapy (IMRT), and stereotactic radiosurgery and brachytherapy. These newer treatment modalities deliver greater doses of radiation to the tumor, which accounts for their increased effectiveness when compared to standard external beam radiation therapy.

To achieve continued improvements in the management of localized cancers with radiotherapy, further dose escalation is necessary because a dose response relationship for radiotherapy exists for most cancers. However, with the increased dose of delivered radiation comes the potential for increased complications to healthy tissues, unless measures are taken to reduce the amount of adjacent normal tissue irradiated. Effective radiation treatments are dependent upon both total dose of radiation and the volume of normal tissue irradiated around the tumor. Therefore, as the radiation dose is increased, the volume of adjacent normal tissue irradiated must be decreased in order to keep an equivalent rate of effective radiation treatment.

To reduce the amount of adjacent normal tissue that is irradiated, one must prescribe the radiation to the target with a tighter treatment margin, that being an area of healthy tissue around the target that receives the full dose of prescribed radiation. For example, if the treatment margin for prostate cancer is too large, the margin may encompass some rectal, bladder and bulbar urethral tissues. It is highly desirable to provide a margin that does not encompass these important tissues.

It would be ideal to have no treatment margin at all. Some margin has been necessary, however due to day-by-day variability in the initial radiation treatment

setup and delivery with existing systems. Margins have also been needed to accommodate for potential internal movement of a target within the patient's body that can occur even when the exterior portion of the patient remains stationary. Several studies have documented and quantified that tumor motion in the prostate occurs during radiation treatment, primarily due to the patient's breathing, and due to natural rectal and bladder filling and emptying. Without some treatment margin, the potential exists that the tumor itself could move out of the treatment volume.

In addition, if the patient is set up so the radiation beam is initially off target, or if the target moves during treatment, the beam hits more of the normal tissue and causes increased collateral damage to the normal tissue, as well as potentially under-dosing the target. It is highly desirable to prevent as much collateral damage to normal tissue as possible. Thus, day-by-day, minute-by-minute changes in radiation treatment setup and target motion have posed serious challenges when dose escalation is attempted with current patient setup processes.

Current patient setup procedures are reliant upon alignment of external reference markings on the patient's body with visual alignment guides for the radiation delivery device. As an example, a tumor is identified within a patient's body with an imaging system, such as an X-ray, computerized tomography (CT), magnetic resonance imaging (MRI), or ultrasound system. The approximate location of a tumor in the body is aligned with two or more alignment points on the exterior of the patient's body, and external marks are written on the patient's skin to mark the alignment points.

During the patient setup for radiation treatment, the external marks are aligned with a reference system of the radiation delivery devices. This setup process attempts to accurately position the treatment target (or patient) isocenter within the body at a position in space where the radiation beam is focused, known as the machine isocenter. By precisely positioning the treatment target with respect to the machine isocenter, the effective patient treatment volume within the body is accurately registered (or positioned) to the radiation therapy treatment plan location. If, however, the target has moved relative to the external marks, then the target may be offset from the machine's isocenter, even when the external aligning devices and marks are properly aligned. Accordingly, the doctors and technicians cannot tell how far the

target has actually moved relative to the machine's isocenter. As an example, studies have documented target displacements of up to 1.6 cm between two consecutive days of prostate radiotherapy treatment. Substantial target displacement of lung tumors in a very short time period has also been documented because of the patient's breathing  
5 and heartbeats. Such internal motion of the target can cause inaccuracies in treatment deliveries, so larger margins of healthy tissue are prescribed and irradiated to compensate for likely internal target motions.

## SUMMARY

Under one aspect of the invention, a system and methods are provided  
10 for accurately locating and tracking the actual position of a target within a body in preparation for and during radiation therapy. In one embodiment, the system is usable with a radiation delivery source that delivers a selected dose of radiation to the target in the body when the target is positioned at the machine isocenter of the radiation delivery source. The system includes a beacon fixable in or on the body at a selected  
15 position relative to the target, such as in or near the target. The beacon is excitable by an external excitation source to produce an identifiable signal while affixed in or on the body. A sensor array with a plurality of sensors is provided external of the body, and the sensors are spaced apart in a known geometry relative to each other.

A data-processing unit is coupled to the sensor array and is configured to  
20 use the measurements from the sensors to determine the actual location of the beacon and a target isocenter within the target relative to the sensors. A reference marker is also coupled to the radiation delivery device at a known position relative to the device's machine isocenter. The reference marker provides a measurable signal for determining the position of the reference marker and the machine isocenter relative to  
25 the sensor array. The data-processing unit is configured to compare the position of the target isocenter with the position of the machine isocenter in real time to determine whether the patient is properly setup for the radiation therapy.

Under another aspect of the invention, a monitoring system is coupled to the data-processing unit and has a feedback portion configured to provide feedback  
30 information about the actual position of the target isocenter relative to the machine isocenter. In one embodiment, the feedback portion provides a visual and/or numeric

representation of the positions of the machine isocenter and target isocenter relative to each other. This representation may then be used to adjust the position of the target isocenter before or during therapy. In another embodiment, the feedback portion provides a visual and/or numeric display of the real-time movement of the target isocenter relative to the machine isocenter. Additionally, the feedback data may be used to automatically alert the operator of patient or target movement beyond acceptable limits. In a third embodiment, the feedback data may be used to automatically adjust, gate or shutoff the radiation therapy treatment for normal (i.e. respiration) or unplanned patient motion.

Under another aspect of the invention, an adjustable patient support assembly is combined with the tracking and monitoring system for use with the radiation delivery system. The support assembly includes a base, a support structure movably attached to the base, and a movement control device connected to the support structure in order to selectively move the support structure relative to the base. The plurality of sensors spaced apart from each other are coupled to the base in a fixed location relative to the base. The data-processing unit is coupled to the sensors to receive the signal measurement data from one or more beacons in or next to the target. The data-processing unit is configured to use the signal measurement data for each beacon to determine the actual location of the beacon and target isocenter within the target. The data-processing unit is configured to identify the location of the target isocenter relative to the machine isocenter. The movement control device is coupled to the data-processing unit and is adapted to position the target isocenter coincident with the machine isocenter in response to data from the data processing unit.

Under another aspect of the invention, a method is provided for delivering radiation therapy on a selected target within a body. The method includes positioning an excitable beacon at a selected position relative to the target, exciting the implanted beacon with an excitation source external of the body to produce an identifiable beacon signal and measuring the beacon signal from the beacon with a plurality of sensors exterior of the body, positioned in a known geometry relative to each other. The method also includes determining the location of the beacon and a target isocenter in the body relative to the sensors based upon the measurements of the beacon signal from the sensors. The method further includes determining the location

of a machine isocenter of the radiation delivery assembly relative to the sensors and relative to the target isocenter, and positioning the body relative to the radiation delivery device so the target isocenter is coincident with the machine isocenter. Radiation therapy is then applied from the radiation delivery device to the treatment 5 volume about the target isocenter.

In yet another aspect of the invention, a method is provided for positioning a body relative to a radiation delivery device for delivering radiation therapy to a treatment volume at a target isocenter within the body. The body has a selected target therein, and at least one excitable beacon is positioned in a known 10 position relative to the target. The method includes positioning the body on a movable support assembly adjacent to a plurality of sensors, and energizing the excitable beacon with an excitation source exterior of the body. The excited beacon provides an identifiable beacon signal. The beacon signal is measured with the plurality of sensors positioned exterior of the body and in a known geometry relative to each other and 15 relative to the movable support assembly. The location of the beacon and a target isocenter within the treatment volume is determined based on the measurements by the sensors of the beacon signal. The location of the target isocenter is also determined relative to the plurality of sensors and relative to the machine isocenter. The location of the target isocenter is compared to the location of the machine isocenter, and if the 20 two isocenters are not coincident with each other, a portion of the support assembly moves the body and target to position the target isocenter coincident with the machine isocenter.

#### BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic side elevation view of a target locating and 25 monitoring system in accordance with an embodiment of the present invention. Excitable beacons are shown implanted in or adjacent to a target in a patient's body, a sensor array is shown exterior of the patient, and a radiation delivery device is shown in a position to apply radiation therapy to the target within the body.

Figure 2 is a schematic top plan view of the patient on a movable 30 support table, with the implanted beacons, the target, and the sensor array shown in hidden lines.

Figure 3 is an enlarged side elevation view of one embodiment of a single-axis beacon usable in the system illustrated in Figure 1.

Figure 4 is an enlarged side elevation view of one embodiment of a three-axis beacon usable in the system of Figure 1.

5 Figure 5 is an enlarged isometric view of another embodiment of a three-axis beacon usable in the system of Figure 1.

Figure 6 is an enlarged partial schematic isometric view of the target, three beacons implanted in or near the target, an external excitation source, the sensor array, and a computer controller in the system of Figure 1.

10 Figure 7 is a schematic isometric view of an alternate embodiment of the sensor array in the system of Figure 1.

Figure 8 is a geometric representation of two intersecting spheres representing data for determining a beacon's position relative to two sensors.

15 Figure 9 is a geometric representation of four intersecting spheres representing data for determining a beacon's position relative to four sensors.

Figure 10 is a schematic isometric view of a target in a body shown in phantom lines in a first position and shown in solid lines in a second, different position within the body.

20 Figure 11 is an enlarged isometric view of the monitoring system of Figure 1 showing a simulated target, simulated beacons, and a simulated target isocenter shown in phantom lines on a display screen, and actual beacon locations and target isocenter locations shown in solid lines on the display screen.

25 Figure 12 is an isometric view of the monitoring system of Figure 11 with the simulated and actual beacons shown aligned with each other, and the machine isocenter and target isocenter coincident with each other.

Figure 13 is a simulated isometric view of a target and beacons illustrated on the monitoring system, and the target is shown in a first target condition.

30 Figure 14 is a simulated isometric view of the target and beacons of Figure 13, and the target is shown in a second condition representing a change in the target size or condition relative to the beacons.

Figure 15 is a side elevation view of an alternate embodiment of the present invention with surface beacons mounted to an external surface of the patient's body and in alignment with each other and the target.

Figure 16 is a top plan view of all of the patient with the surface-mounted beacons of Figure 15 mounted thereon.

Figure 17 is a schematic flow diagram of a radiation delivery process for delivering radiation treatment to a target utilizing the system of Figure 1.

#### DETAILED DESCRIPTION

Figures 1-17 illustrate a system and several components for locating, tracking and monitoring a target within a body in accordance with embodiments of the present invention. The system and components are usable to locate, track, monitor, and evaluate a target for application of a selected therapy to the target, such as guided radiation therapy. Several of the components described below with reference to Figures 1-17 can also be used in systems for performing methods in accordance with aspects of the present invention. Therefore, like reference numbers refer to like components and features throughout the various figures.

Referring to Figures 1 and 2, one aspect of the present invention provides a system 10 configured for use in applying guided radiation therapy to a target 12, such as a tumor, within the body 14 of a patient 16. The system 10 allows the target 12 to be located within the patient's body 14 and the actual position monitored in real time while applying ionizing radiation therapy to the target from a radiation delivery source 18. The target 12 may move within the body 14 because of breathing, organ filling or emptying, or other internal movement. The target motion is tracked and monitored relative to the radiation beam to insure accurate delivery of radiation to the target 12 and, if needed, only a minimum margin around the target. While the system 10 is discussed below in connection with guided radiation therapy for radiation of a tumor or other target, the system can be used for tracking and monitoring other targets within a body, such as for other therapeutic or diagnostic purposes.

The radiation delivery source 18 of the illustrated embodiment (Figure 1) is an ionizing radiation device, known as a linear accelerator, but could be any

radiation therapy delivery device. Other radiation therapy delivery devices can be used, including such devices manufactured by Varian Medical Systems, Inc. of Palo Alto, California; Siemens Medical Systems, Inc. of Iselin, New Jersey; Electa Instruments, Inc. of Iselin, New Jersey; or Mitsubishi Denki Kabushik Kaisha of Japan. Such devices are used to deliver conventional single or multi-field radiation therapy, 3D conformal radiation therapy (3D CRT), inverse modulated radiation therapy (IMRT), stereotactic radiotherapy, tomo therapy. This is done in conjunction with a variety of treatment planning software systems.

The radiation delivery source 18 delivers a gated, contoured or shaped beam 19 of ionizing radiation from a movable gantry 20 to a area or volume referenced to a point at a location away from the gantry. This point in space, referred to as a machine isocenter 22, is the point to which the ionizing radiation beam 19 is configured about as determined by industry standard treatment planning processes. The system 10 allows the target 12 to be accurately positioned at the machine isocenter 22 so the ionizing radiation is accurately delivered to the target 12. The system also allows the target's actual position relative to the machine isocenter 22 to be monitored during the radiation therapy so as to minimize collateral damage to healthy tissue surrounding the target.

The illustrated system 10 includes a plurality of beacons 30 positioned in or adjacent to the target 12 to mark the target's actual location in the body 14. Accordingly, the beacons 30 are markers in, on or near the body. In one example, the beacons 30 may be attached to patient-immobilization devices at known locations relative to the treatment isocenter. The beacons 30 are energized or excited by an excitation source 32 positioned exterior of the patient's body 14. When the beacons 30 are excited, they each resonate at a selected unique frequency and generate a low energy radio-frequency magnetic signal measurable from outside of the body 14. The signals from the beacons 30 are detected and measured by an array 34 of sensors 36 located exterior of the patient's body 14. The sensors 36 are positioned in a fixed, selected geometry relative to each other, so the array 34 defines a fixed reference coordinate system from which location and movement are calculated. The sensors 36 are operatively coupled to a computer controller 38 that receives the measurement

information from each sensor and determines the actual location of the beacons 30 within the patient's body 14 relative to the sensors.

In one embodiment, the computer controller 38 includes algorithms used to define and determine the location of the target isocenter 40 within the target 12, 5 based upon the signal measurements by the sensors 36 from the resonating beacons. In another embodiment, the location of the target isocenter 40 within the target 12 is selected, and the computer controller 38 utilizes position information about the position and/or orientation of each beacon 30 relative to the selected target isocenter. The target isocenter 40 is the point or position within the target to which the shaped 10 dose of radiation is configured around or referenced to as determined by a treatment planning process. In one embodiment, the sensors 36 are polled twelve or more times per minute to track the actual position of the target isocenter 40 within the patient's body 14 relative to the sensor array 34. Accordingly, the actual position of the target 12 and the target isocenter 40 can be monitored in real time when the patient is 15 positioned adjacent to the sensor array 34.

The actual position of the target isocenter 40 is compared to the position of the machine isocenter 22 relative to the sensor array 34. The illustrated system 10 has a reference device 42 positioned on the gantry 20 of the linear actuator or another selected position on a radiation therapy delivery device used in alternate embodiments. 20 In these alternate embodiments, the other radiation therapy delivery device can include cobalt machines, a Gamma Knife, a Cyberknife, specialized stereostatic radiotherapy devices, or a TomoCT assembly (which utilizes a linear actuator in a CT scanner). The reference device 42 is positioned at a known spatial or geometric relationship relative to the machine isocenter 22. The reference device 42 in one embodiment is a 25 resonating, three axis, single frequency beacon that provides a measurable signal detectable by the sensors 36 in the array 34. The reference device 42 in alternate embodiments can be positioned in a remote location away from the gantry 20. In either embodiment, the location of the machine isocenter 22 relative to the sensor array 34 can be calculated upon determining the position of the reference device 42 relative to the sensor array. The sensors 36 provide the measurement data about the 30 reference device 42 to the computer controller 38, and the computer controller calculates the location of the machine isocenter 22 relative to the sensor array 34.

The location of the target isocenter 40 relative to the sensor array 34 is compared to the position of the machine isocenter 22 relative to the sensor array. If the target isocenter 40 and machine isocenter 22 are spatially misaligned such that the two isocenters are not three-dimensionally coincident with each other, the patient 16, 5 and/or target 12 can be moved relative to the machine isocenter 22. The target 12 position is moved until the target isocenter 40 is coincident with the machine isocenter 22. Once the target and machine isocenters 40 and 22 are acceptably aligned, the radiation delivery source 18 can be activated to provide the ionizing radiation beam 19 referenced to the target isocenter, thereby irradiating the target according to a radiation 10 treatment plan, while minimizing or eliminating collateral damage to healthy tissue surrounding the target 12. The actual location of the target isocenter 40 can also be monitored in real time during the radiation therapy to ensure that the target isocenter does not move an unacceptable amount relative to the machine isocenter 22 and allow 15 for treatment when the treatment isocenter and the machine isocenter are within acceptable displacement limits.

In the illustrated embodiment, the system 10 also includes a monitoring assembly 44 coupled to the computer controller 38 that provides feedback data to a user interface for the doctor or technician operating the system and/or the radiation delivery device 18. As an example, the monitoring assembly 44 can provide the 20 feedback data as a visual representation of the target isocenter's position in three-dimensional space relative to the machine isocenter's position in real time as the patient is being set up and positioned for the radiation therapy. The monitoring assembly 44 can also provide other feedback data to the user interface including, for 25 example, confirmation of setup completion, graphical information, patient information, radiation treatment plan information, or other information that can be utilized during the guided radiation therapy process.

Figures 3-5 illustrate excitable beacons 30 of alternate embodiments usable in the system 10. One of the beacons 30 shown in Figure 3 is an implantable, single-axis, resonating beacon 31 having a ferrite core 46 wrapped by a conductive 30 winding 48, and the winding is connected to a small capacitor 50. The beacon 31 is configured to be energized by the external excitation source 32, which produces an electromagnetic field. This electromagnetic field causes the beacon 31 to resonate at a

predetermined frequency, thereby providing a signal of sufficient intensity to be measured by the sensors 36 (Figure 1) from outside of the body. A biologically inert coating 52 encapsulates the ferrite core 46, the winding 48, and the capacitor 50 so as to provide a small, self-contained, wireless excitable beacon 31 that can be 5 permanently implanted into the patient. In this embodiment, the beacon 31 is "wireless" because it need not be physically connected via wires to an outside energy source for generation or communication of the beacon signal. In one embodiment, the beacon 31 has a length of only approximately 5 mm and diameter sized to fit through an applicator needle. The beacon 31 in other embodiments can have different sizes as 10 needed for the desired configuration of the beacon signal.

As best seen in Figure 4, another one of the excitable beacons 30 includes a three-axis, wireless, resonating beacon 52 with three signaling portions 54. Each signaling portion 54 is positioned axially perpendicular to the other two signaling portions. Accordingly, the three signaling portions 54 define an X, Y, Z 15 reference coordinate. Each of the signaling portions 54 includes a ferrite core 46, a winding 48 around the ferrite core, and a small capacitor 50 connected to each winding. Each signaling portion is configured to be energized by the external excitation source 32, and to resonate at a frequency different than the resonating frequency of the other two signaling portions.

In one embodiment, as illustrated in Figure 4, the three-axis beacon 52 20 includes a biologically inert coating 56 that encapsulates all three of the signaling portions 54, so the beacon can be permanently implanted in the patient's body. When the beacon 52 is energized by the external excitation source 32, each of the beacon's signaling portions resonates at its selected frequency and provides the measurable 25 beacon signal at an intensity so it can each be measured by the sensor array 34 (Figure 1). Frequency multiplexing by the computer controller allows the computer controller 38 to differentiate between the beacon signals from the different signaling portions of the beacon when calculating the beacon's position and orientation relative to the sensor array.

As best seen in Figure 5, another embodiment of the beacon 30 includes 30 a cube-shaped beacon 58 with a single ferrite core 60 and three sets of windings 62 axially oriented perpendicular to each other to define the X, Y, and Z axes for the

beacon. Each winding 62 is connected to a small capacitor 64 and configured to resonate at a frequency different than the other two windings. Accordingly, the cube-shaped beacon 58 is also a wireless, three-axis, resonating beacon.

In one embodiment, the wireless, excitable beacons 30 are configured to resonate and provide a measurable signal within the frequency range of approximately 5 10kHz to 200kHz, inclusive. In other embodiments, the beacons 30 can be self-contained, powered markers that include a power source, such as a battery, that provides sufficient power to produce the measurable identifiable beacon signal. In other embodiments, the beacons 30 can be "wired" beacons connectable via wires to a 10 selected power or excitation source to allow the beacons to generate the unique beacon signal. The beacon signal can be unique as a function of frequency (i.e., frequency multiplexing) as a function of time or time multiplexing.

In selected applications, a single beacon 31, preferably a singleaxis beacon, is implanted in the target 12, and the intensity of the signals from the single 15 resonating beacon is used to determine the target location information relative to the sensor array 34. In alternate embodiments, two, three, or more beacons 30 are implanted at known locations in or adjacent to the target. Each beacon 30 produces its unique signal relative to the other beacons, so the sensor array 34 differentiates between the beacons by frequency multiplexing. The sensor array 34 measures the 20 intensity of the unique signals from the beacons 30. The signal intensity measurements are converted for use in geometric calculations (discussed in greater detail below) to accurately determine the actual three-dimensional location (X, Y, Z) and possibly the angular orientation (pitch, yaw, roll) of the beacon relative to the sensor array 34.

25 Referring again to Figure 1, the system 10 includes the excitation source 32 that generates a magnetic field for exciting the beacons 30. The excitation source is positioned in a selected location relative to the target 12 and close enough to the beacons 30 so the emitted magnetic field has sufficient intensity to acceptably energize the beacons. In the illustrated embodiment, a plurality of beacons 30 are 30 permanently implanted within the patient's body 14 in or adjacent to the target 12. In one embodiment, the computer controller 38 provides a separate driver circuit for the excitation source 32 for each beacon 30, so as to selectively excite the respective

beacon at the selected frequency. The excitation source 32 in one embodiment is a three-dimensional, AC magnetic field source that generates three-dimensional magnetic fields in the X, Y, and Z axes. This excitation source 32 provides one source coil for each beacon 30, and the electric current driven through the source coil generates the AC magnetic waveform tuned for the respective beacons. In another embodiment, the source coil (or coils) in the excitation source 32 is provided by a coils configured to generate the multiple or scanned excitation frequency fields for the respective beacons 30.

Figures 6 and 7 are schematic isometric views of sensor arrays 34 positionable exterior of the body (Figure 6) and spaced apart from the beacons 30 positioned in or near the target 12. In these illustrated embodiments, three beacons 30 are shown implanted in or near the target 12. As seen in Figure 6, the sensor array 34 includes a frame 70 that supports a plurality of sensors 36 in a fixed and known geometry relative to each other along X, Y, or Z axes of a reference coordinate system 72. The position of each sensor 36 on the frame 70 relative to the reference coordinate system 72 is fixed and defines fixed reference points for obtaining measurement data used by the computer controller 38. In the embodiment of Figure 6, the frame 70 supports the sensors 36 so the sensors are positioned in a single plane. In the embodiment of Figure 7, the frame 70 is shaped to support the sensors 36 in two orthogonal planes, so the sensors 36 are oriented along the X, Y, and Z axes of the reference coordinate system 72. Accordingly, the sensor array 34 provides the fixed reference structure from which measurements are taken and calculations performed to determine the relative positions of the target 12, the target isocenter 40 and the machine isocenter 22.

The illustrated embodiments of Figures 6 and 7 utilize "wireless" beacons 30, so frequency multiplexing is utilized to distinguish the signals from the different beacons. Each sensor 36 is a three-axis sensor that measures the absolute beacon signal strengths from a respective one of the beacons 30 relative to the X, Y, and Z axes. The absolute signal strength of the beacon signal along each axis in the reference coordinate system 72 is measured by the sensors 36 for each beacon in order to determine the X, Y, and Z position of each beacon.

It is known that the strength of a magnetic field decreases at a ratio proportional to the cube of the distance from the source. Accordingly, the distance of the beacon from the sensor can be determined based upon the beacon's signal strength. The geometric relationship from the beacon to a series of sensors that are spaced at 5 known locations relative to each other is used to solve a series of equations with one unique result. Accordingly, the distance between the beacon 30 and the sensor 36 calculated by the computer controller 38 based on the beacon's signal strength measured by the respective sensors and iterated for a best fit solution to the geometric equations.

10                 The precise location of a beacon 30 in space relative to the sensor array 34 can be calculated based upon the distances between that beacon and at least four separate three-axis sensors spaced apart from each other in the array. The absolute magnitude of the distance from the three-axis sensor is determined by squaring the each of the three axis magnitudes (x, y, and z orientations), adding the results and 15 finally taking the square root for the distance resultant. As an example, the distance between one sensor 36 and one of the beacons 30 corresponds geometrically to the radius of a sphere. Figure 8 shows two illustrative spheres 100 with the center points 102 each defined by a separate sensor 36. When two spheres 100 intersect, the intersection defines a circle 104. So, it is known that the beacon is located at some 20 point on that circle. When three spheres 100 intersect, shown in Figure 9, the intersection defines one of two points 105 where the beacon is located on that line. When four spheres 100 intersect, the intersection defines a single point 108 in space corresponding to the precise position of the beacon 30 in space relative to the sensor array 34.

25                 In an embodiment using a single beacon 30 implanted in a target 12, the sensor array 34 can include only four three-axis sensors 36 to determine that beacon's position in space. Since the signals are frequency multiplexed and multiple frequencies may be received with each sensor coil and each individual frequency component may be examined by processing the combined signal with a fast Fourier 30 transform (FFT) in the control electronics, multiple beacons may be located with the same sensors. In the embodiments with three or more beacons 30 positioned in or near the target 12, the sensor array 34 is configured at known geometric orientations

relative to the reference coordinate system 72, so that the beacon signal measurements can be used by the computer controller 38 to calculate the angular orientation of the treatment volume (i.e., the pitch,yaw and roll) in space relative to the reference coordinate system 72 by using the three sets of three dimensional data (x, y, and z from the single axis beacons). Based upon the position of the beacons 30 relative to the target, the location and angular orientation of the target 12 can be determined by the computer controller 38.

- The beacon signal may be separated from the signal generated by the excitation source 32 via signal processing software or electronics in a number of ways.
- 10 In one embodiment, the excitation source 32 is turned or gated "on" to excite the beacon and then turned or gated "off" to allow for measurement of the beacon response without interference by the signal from the excitation source. The beacon 30 will continue to resonate after the excitation source 32 is gated "off" for a period determined by the sensor's electric inductance, capacitance and series resistance. In
  - 15 another embodiment, the system is operated in continuous wave (CW) mode were the excitation source 32 remains "on" during measurement of the beacons 30. The beacon signal is 90 degrees "out of phase" with the signal from the excitation source, so the beacon signal is removed from the excitation signal. The time of the zero crossing of the excitation signal is known and the remaining beacon signal will be at its peak intensity at that time. In a third embodiment, the output frequency of the excitation source's signal is continuously varied or scanned to maximize the excitation of the beacons 30 which results in a maximum beacon signal while minimizing or eliminating unwanted excitation signal.

The position of each beacon 30 relative to the target 12 and relative to the target isocenter 40 is also calculated or determined. In one embodiment, the target isocenter 40 in the target 12 is chosen first based upon imaging data about the target provided by an imaging system, such as a CT scan, MRI, ultrasound system, or nuclear imaging system (e.g. positron emission tomography). Once the target isocenter 40 is selected, the position of each implanted beacon 30 is measured relative to the target isocenter 40. The position of the target isocenter 40 is then determined relative to the reference coordinate system 72 based upon defining the location of each beacon 12 relative to the reference coordinate system.

In another embodiment, the target isocenter 40 is defined as a function of the beacon locations relative to the target 12. The beacons 30 are selectively positioned in or near the target 12 and the orientation of the beacons is used to define and calculate the target isocenter. Thus, the target isocenter 40 within the target 12 can be defined and its position determined relative to beacons 30 and the reference coordinate system 72 even if the beacons 30 are not actually implanted within or even immediately adjacent to the target 12. The beacons 30 are, however, positioned close enough to the target 12 so that if the target moves, the target and beacons move together substantially as a unit. Therefore, movement of the target 12 is monitored by tracking movement of the beacons 30 relative to the sensor array 34.

The system 10 is configured to track motion of the target 12 in real time. When the portion of the patient's body 14 containing the target 12 and beacons 30 is positioned adjacent to the sensor array 34 and the beacons are energized, the computer controller 38 acquires data from each sensor 36 and outputs a result approximately 12 times per second. The computer controller obtains measurement data from the sensors 36 and calculates the location of the target isocenter 40 relative to the sensor array every five seconds. In alternate embodiments, the computer controller 38 can measure the sensors 36 to monitor in real time the motion of the particular target isocenter 40 relative to the sensor array 34. The measurement update rate may be reduced as to allow for sufficient data averaging to reduce the measurement noise at the same time allowing for an adequate update rate for the user.

Figure 10 is a partial isometric view illustrating an aspect of the present invention that includes a support table 76 that movably supports the patient's body 14 under the gantry 20 and adjacent to the sensor array 34. The support table 76 is positionable below the machine isocenter 22. The support table 76 is movable to adjust the position of the patient 16 relative to the machine isocenter 22 until the target isocenter 40 is coincident with the machine isocenter. The sensor array 34 may be placed on, under, or connected to the support table 76. Alternatively, it may be mounted to the linear accelerator's gantry at a location sufficiently close to any beacons 30 (implanted, external or gantry) that are to be located. In this alternate embodiment with the sensor array 34 mounted to the linear accelerator, the position

from the machine isocenter 22 to the sensor array will be known, so that a separate gantry beacon 42 may not be used.

As best seen in Figures 1 and 10, the support table 76 has a base 88 and a tabletop 90 movably supported to the base for linear and angular movement relative to the sensor array 34. A movement control system 78 is connected to the tabletop 90 to control movement of the tabletop and the patient 16 relative to the machine isocenter 22 and the sensor array 34. The control system 78 is also coupled to the computer controller 38, and the computer controller 38 is programmed to activate the control system 78 to adjust the linear or angular position of the patient. In one embodiment, the tabletop's position moves in response to an authorized user such as doctor, physicist or technician activating the control system, or automatically in response to instructions provided by the computer controller 38.

Once the target 12 is positioned so the target isocenter 40 is coincident with the machine isocenter 22, ionizing radiation can be selectively and very accurately delivered directly to the target area or volume. Application of the radiation therapy to the target 12, can be provided at the selected dosage and intensity with precise accuracy, while potentially minimizing the margin needed around the target. In one embodiment, the actual position of the target isocenter 40 is substantially continuously monitored and tracked relative to the machine isocenter 22 during delivery of the radiation therapy. If the target isocenter 40 moves away from the machine isocenter 22 beyond an acceptable range of displacement distances, the computer controller 38 provides a signal to the radiation delivery device to interrupt the radiation therapy to the target. The target's position can then be adjusted manually or automatically until the target isocenter 40 is again coincident with the machine isocenter 22, and radiation therapy can resume. In one embodiment, the computer controller 38 is programmed so that if the target isocenter 40 moves from the machine isocenter 22, but the distance of movement does not exceed the acceptable range, the computer controller 38 will not interrupt the radiation therapy. This range of movement is dependent upon many factors, such as the target type (e.g., prostate, lung, liver), target size, target location, beam shape/size, and the radiation treatment plan.

Tracking of the target isocenter's position is facilitated by the monitoring assembly 44, which is coupled to the computer controller 38. Figures 11 and 12 illustrate a feedback portion 80 of the monitoring assembly 44 that provides feedback data to an operator about, as an example, the position of the beacons 30, the target isocenter 40 and the machine isocenter 22. The feedback portion 80 is a display monitor that provides pictorial, graphical, or textual information to the operator. Other feedback portions 80, such as graphical display devices, auditory feedback devices, or visual feedback devices can be used in alternate embodiments. In one embodiment, the computer controller 38 contains imaging data, such as from a CT, MRI, or ultrasound imaging system, that defines the shape and size of the target 12 within the body 14. The imaging data also defines the locations of each beacon 30 in or around the target 12. The computer controller 38 uses the imaging data to provide a simulated model of the target, the beacons, and the target isocenter. This simulated model is displayed on the feedback portion 80 as shown in Figure 11 in phantom lines. 10 The simulated model is also displayed overlaying the machine isocenter 22, so the simulated target isocenter 40 is coincident with the machine isocenter. The simulated target and simulated beacons can also display how the actual target needs to be positioned and oriented three-dimensionally for the particular radiation therapy to be applied to the target.

20 The monitoring assembly 44 also receives and display information from the computer controller 38 to show the actual locations of the beacons 30 and target isocenter 40 relative to the machine isocenter 22, and relative to the simulated target and beacons. Accordingly, the feedback portion 80 allows the operator to determine the actual position of the beacons relative to the simulated beacons, and the target isocenter 40 relative to the machine isocenter 22 substantially in real time while the patient 16 is on the support table 76 (Figure 1). The patient 16 and support table 76 25 can be repositioned until the target 12 is properly oriented for the selected radiation therapy.

In addition to accurately tracking and monitoring the position of the target 12 relative to the machine isocenter 22, the system 10 is also usable to monitor the status of the target, such as a tumor or the like, in a patient's body 14 over time. 30 Figures 13 and 14 are schematic views showing a tumor 90 in a body 92. Three

beacons 30 are shown for this embodiment permanently implanted in or adjacent to the tumor 90. Images of the tumor 90 and beacons 30 are obtained by CT, MRI, ultrasound, or other imaging technique over time. From these multiple images of the tumor 90 and beacons 30, the position of the beacons relative to the tumor can be 5 compared and tracked. Accordingly, a doctor can use the beacons 30 in the multiple images as a reference tool to determine whether the tumor has shrunk, grown, moved, or otherwise changed within the patient's body.

As an example, Figure 13 illustrates an image of a tumor 90 in a first condition with three beacons 30 implanted therein, and Figure 14 illustrates a second 10 image of the tumor taken later in time. The second image shows the same beacons 30 in the same location within the patient's body, and from the position of the tumor relative to the beacons, one can see that the tumor has shrunk. Thus, doctors can track the status of tumors or other targets within the body over time to determine, as an 15 example, the effectiveness of radiation therapy, whether additional treatments are needed, or whether a change in tumor growth has occurred or whether the radiation treatment plan needs to be altered.

In the embodiments discussed above, the beacons 30 are described and shown as being subcutaneously implanted in or next to a target 12. This implantation of the beacons 30 is performed when needed to ensure that, if the target 12 moves, the 20 beacons will move with the target as a unit. In an alternate embodiment illustrated in Figures 15 and 16, the beacons are surface-mounted beacons 110 adhered to the exterior surface 112 of the patient's body 14 substantially adjacent to and in alignment with a target 12, in or on the body. The surface-mounted beacons 110 can be removably adhered with an adhesive, such as tape or the like, in a substantially fixed 25 location on the body's exterior surface 112 relative to the target 12. These surface-mounted beacons 110 are particularly suitable for targets 12 known not to substantially move within the body 14 relative to the exterior surface. The surface-mounted beacons 30 are also suitable for use when the target's size or location in the body 14 is such that some motion of the target isocenter is not critical for effective 30 radiation therapy or treatment. Accordingly, the surface-mounted beacons 110 provide reference points for accurate alignment and orientation of the target 12 and the

machine isocenter 22. Alternatively, beacons 30 may be mounted on or in patient immobilization devices at known locations relative to the treatment isocenter.

The surface-mounted beacons 110 in one embodiment are wireless beacons, so that the beacons can remain adhered on the patient's body 14 after a radiation treatment session so that the patient 16 can come and go from the treatment area without disrupting the position of the beacons 110 relative to the target 12. In alternate embodiments, the beacons 110 remain adhered to the patient 16 and are connectable to lead wires of a "wired" marker system in the treatment area. The lead wires can be disconnected from the beacons 110 to allow the patient 16, to leave the treatment area while the beacons remain fixed in place on the patient's body.

The surface-mounted beacons 110 are also usable to monitor a patient's base-line girth (anterior-posterior and lateral dimensions) during a radiation treatment program. The base-line girth measurements, referred to as patient separations, are initially obtained by CT, MRI, or physical measurements. Patient separations are used when preparing a radiation treatment plan for the patient. The surface-mounted beacons 100 can be utilized alone or in combination with implanted beacons to provide data about changes in the patient separations that may occur during chemo or radiotherapy. Each surface-mounted beacon 110 has an identifiable initial position in space relative to, as an example, the target isocenter or relative to each other. The sensor array 34 and computer controller 38 are configured to determine the distances between each surface-mounted beacon and/or the target isocenter. The computer controller 38 calculates and monitors the distances, corresponding to the patient separations. During the course of radiation treatment, if the patient separations change significantly, such as due to substantial weight loss from chemo or radiotherapy, the treatment plan may become invalid because less patient tissue is available to alternate the radiation beam, thereby resulting in higher than planned doses of radiation.

In one embodiment, the surface-mounted beacons 110 are usable to facilitate and speed up patient set-up procedures before and/or during the radiation therapy procedure. The surface mounted beacons 110 are positioned at selected locations on the patient's body 14 at known positions. The beacons 110 are excited and the locations relative to the sensor array are determined. The beacon's location information can then be used to calculate the Target Skin Distance or Source Skin

Distance, which is the distance between the exterior skin of the patient and the linear actuator or the tabletop. The beacons 110 can also be used to determine the tabletop-to-isocenter, which is the distance between the tabletop to the beacon or other alignment means, such as laser cross-hairs projected on to the patient's skin.

- 5 Accordingly, the surface mounted beacons 110 can be used to automatically calculate the relevant distances during the set up procedure to quickly determine if the patient is properly positioned in accordance with the radiation therapy treatment plan.

In another embodiment, the surface-mounted beacons 110 can be used in conjunction with one or more beacons 30 implanted in or near the target 12. The 10 relative location of each beacon 110 or 30 can be calculated and used for any combination of patient set-up, target locating, target positioning, target motion tracking, and/or target evaluation, as discussed above.

The system 10 is also adapted for use in an automated patient setup process prior to delivery of the radiation therapy. The automated setup process of one 15 embodiment is shown schematically as a flow chart in Figure 17. In this patient setup process, the tumor or other target in the patient's body is identified (reference block 150). Images of the target are obtained (reference block 152), such as by X-rays, CT, MRI, nuclear, or ultrasound imaging. The doctor and/or technicians then determine a treatment plan for the particular tumor (reference block 154). One or more beacons 20 are implanted in or on the body in selected positions relative to the target (reference block 156), and the location of the treatment isocenter relative to the beacons is determined or calculated (reference block 158).

The patient is positioned on the movable support table so the target and beacons are generally adjacent to the sensor array (reference block 160). The 25 excitation source is activated to energize the beacons (reference block 162), and the sensors measure the strength of the signals from the beacons (reference block 164). The computer controller calculates location of the beacons and the target isocenter relative to the sensor array and the machine isocenter (reference block 166). The computer compares the position of the target isocenter and machine isocenter 30 (reference block 168), and if the two isocenters are misaligned, the computer automatically activates the control system of the support table to move the tabletop

relative to the machine isocenter until the target isocenter is coincident with the machine isocenter (reference block 170).

In one embodiment, the computer controller also determines the position and orientation of the beacons relative to the position and orientation of simulated beacons. If the beacons are not properly aligned and oriented with the simulated beacons, the support table is adjusted linearly and angularly as needed for proper beacon alignment. This beacon alignment properly positions the target volume along 6 dimensions, namely X, Y, Z, pitch, yaw, and roll. Accordingly, the patient is automatically positioned in the correct position relative to the machine isocenter for 10 precise delivery of radiation therapy to the target.

In one embodiment of this automated setup process, the computer restricts the radiation delivery device from delivering the radiation beam until the target isocenter is coincident with the machine isocenter. The computer monitors the position of the target isocenter during delivery of the radiation treatment (reference 15 block 172). If the target isocenter's position is outside a permitted degree or range of dislocation, the computer interrupts the delivery of the radiation isocenter (reference block 174). The computer can then automatically reposition the tabletop and the patient (as a unit) so the target is properly positioned with the target isocenter and is coincident with the machine isocenter (reference block 176), and the radiation therapy 20 can be reactivated for continued irradiation of the target (reference block 178). If the delivery of the radiation therapy is not yet completed (reference block 180), the process returns to reference block 172 to monitor the target's position relative to the machine isocenter as the radiation is being delivered. Accordingly, adjustments can be made automatically to ensure that the radiation is accurately delivered to the target 25 without requiring a large margin around the target.

Although specific embodiments of, and examples for, the present invention are described herein for illustrative purposes, various equivalent modifications can be made without departing from the spirit and scope of the invention, as will be recognized by those skilled in the relevant art. The teachings 30 provided herein of the aspects of the present invention can be applied to locating, monitoring, and treating a target within a body, and not necessarily limited to the illustrative radiation treatment of the tumor in the body as described above.

In general, in the following claims, the terms used should not be construed to limit the invention to the specific embodiments disclosed in the specification and the claims, but should be construed to include all target locating and monitoring systems that operate in accordance with the claims to provide apparatus and methods for locating, monitoring, and/or tracking the position of a selected target within a body. Accordingly, the invention is not limited, except as by the appended claims.

## CLAIMS

We claim,

1. A target locating and tracking system usable with a radiation therapy delivery source that delivers radiation to a target in a body, the radiation being delivered to a predetermined volume configured around a machine isocenter spaced apart from the radiation delivery source, comprising:

a beacon fixable at a position relative to the target in the body, the beacon being excitable by an external excitation source to produce an identifiable beacon signal from the beacon while in the body;

sensors spaced apart from each other in a known geometry relative to each other and positioned to identify the beacon signal from the beacon, the sensors being configured to measure the beacon signal and to provide beacon measurement signals;

a reference device positionable at a selected position relative to the radiation therapy delivery source and the machine isocenter, the reference device configured to produce a reference signal measurable by a plurality of the sensors; and

a data processing unit coupled to the sensors to receive the beacon measurement signals, the data processing unit being configured to use the beacon measurement signals to determine the location of the target volume with a target isocenter and the location of the reference device relative to the plurality of sensors, and the data processing unit being configured to identify the location of the target isocenter relative to the machine isocenter.

2. The target locating and tracking system of claim 1, further comprising a plurality of beacons implantable in the body, each beacon being excitable by the excitation source to produce a unique beacon signal measurable by the plurality of sensors.

3. The target locating and tracking system of claim 2 wherein the plurality of beacons includes at least three beacons.

4. The target locating and tracking system of claim 3 wherein the beacons are each axially misaligned with each other.

5. The target locating and tracking system of claim 2 wherein the beacon signal from each beacon has a unique frequency different from the frequency of other beacon signals.

6. The target locating and tracking system of claim 1 wherein the beacon is a wireless beacon implantable in the body.

7. The target locating and tracking system of claim 6 wherein the data processing unit is configured to determine the position of the target isocenter relative to the sensors.

8. The target locating and tracking system of claim 1 wherein the beacon is permanently implantable in the body.

9. The target locating and tracking system of claim 1 wherein the beacon is a single-axis, resonating beacon.

10. The target locating and tracking system of claim 1 wherein the beacon is a wireless beacon.

11. The target locating and tracking system of claim 1 wherein the reference device is measurable by a plurality of sensors.

12. The target locating and tracking system of claim 1 wherein the data processing unit is configured to determine the location of the machine isocenter relative to the plurality of sensors and relative to the treatment target isocenter based upon the signal of the linear accelerator reference.

13. The target locating and tracking system of claim 1, further comprising an excitation source remote from the beacon and configured to generate an excitation field that energizes the beacon.
14. The target locating and tracking system of claim 1 wherein the plurality of sensors are fixed to a base in the known geometry to form a sensor array.
15. The target locating and tracking system of claim 1, further comprising a patient support structure shaped and sized to support the body, the plurality of sensors is mounted to the patient support structure.
16. The target locating and tracking system of claim 15 wherein the table structure has a base and a tabletop, the base being in a fixed location relative to the sensors and the tabletop being movably adjustable relative to the sensors.
17. The target locating and tracking system of claim 1, further comprising a monitoring system coupled to the data processing unit, the monitoring system having a feedback portion configured to provide feedback information about the position of the target isocenter and the machine isocenter relative to each other.
18. The target locating and tracking system of claim 17 wherein the feedback portion is a visual display.
19. The target locating and tracking system of claim 17 wherein the data processing unit and monitoring system are configured to identify and display movement in real time of the target and machine isocenters relative to each other.
20. The target locating and tracking system of claim 1 wherein the beacon is one of a plurality of beacons axially misaligned with each other, and the data processing unit is configured to identify a three-dimensional spatial position and orientation of the target relative to the plurality of sensors and the machine isocenter.

21. The target locating and tracking system of claim 1 wherein the reference device is at least one excitable beacon mountable to the radiation therapy delivery source.

22. The target locating and tracking system of claim 1 wherein the reference device is out of physical connection with the plurality of sensors and the data processing unit to provide a wireless interconnection therebetween.

23. A target locating and monitoring system usable with a radiation therapy delivery source that delivers radiation to a target in a body, the radiation being delivered to a treatment volume determined by a machine isocenter spaced apart from the radiation therapy delivery source, comprising:

a plurality of beacons fixable on or in the body at a known geometry relative to each other and relative to the target, the beacons each being excitable by an external excitation source to produce an identifiable beacon signal from the beacon while in the body;

sensors spaced apart from each other and positioned to measure the beacon signals from the beacons, each sensor being configured to provide beacon measurement signals for one or more of the beacons;

a reference device positionable at a selected position relative to the radiation delivery source and the machine isocenter; and

a data processing unit coupled to the sensors to receive the beacon measurement signals from the sensors, the data processing unit being configured to use the beacon measurement signals to determine the location of the target volume having a target isocenter relative to the plurality of sensors, and the data processing unit being configured to identify the location of the target isocenter relative to the machine isocenter.

24. The target locating and monitoring system of claim 23 wherein the signal from each beacon has a measurable signal, and each sensor measures the signal from at least one of the beacons, the computer controller being configured to determine the location and/or spatial orientation of the target within the body based upon measurable signals.

25. The target locating and monitoring system of claim 23, further comprising an excitation source remote from the beacons and configured to operate an excitation field that energizes the beacons.

26. The target locating and monitoring system of claim 23 wherein the plurality of sensors are fixed to a base to define a sensor array positionable as a unit at a selected position remote from the beacons.

27. The target locating and monitoring system of claim 23, further comprising a patient support structure shaped and sized to support the body, the plurality of sensors being in a fixed position relative to a portion of the patient support structure.

28. The target locating and monitoring system of claim 27 wherein the patient support structure has a base and a tabletop.

29. The target locating and monitoring system of claim 23, further comprising a monitoring system coupled to the computer controller, the monitoring system having a feedback portion configured to provide feedback information about the position of the target isocenter and the machine isocenter relative to each other.

30. The target locating and monitoring system of claim 29 wherein the feedback portion is a visual display.

31. The target locating and monitoring system of claim 29 wherein the computer controller and monitoring system are configured to identify and display movement in real time of the target and machine isocenters relative to each other.

32. The target locating and monitoring system of claim 23 wherein the plurality of beacons includes at least three beacons.

33. The target locating and monitoring system of claim 23 wherein the plurality of beacons are axially misaligned with each other.

34. A radiation therapy delivery system usable to irradiate a selected target within a body, comprising

a radiation delivery assembly that delivers radiation from a radiation therapy delivery source to a machine isocenter spaced apart from the radiation delivery source;

a beacon fixable in or on the body at a position relative to the target, the beacon being excitable by an external source to produce a measurable beacon signal while in the body;

a plurality of sensors spaced apart from each other and positioned in a known geometry relative to each other, the sensors being configured to measure the beacon signals and generate beacon measurement signals;

a reference device coupled to the radiation therapy delivery source and positioned remote from the machine isocenter; and

a data processing unit coupled to the sensors to receive the beacon measurement signals, the data processing unit being configured to use the beacon measurement signals to determine the location of the target volume having a target isocenter and the location of the reference device relative to the plurality of sensors, and the data processing unit being configured to identify the location of the target isocenter relative to the machine isocenter.

35. The radiation delivery system of claim 34, further comprising a plurality of beacons implantable in the body, each beacon being excitable by the external source to produce a beacon signal measurable by the plurality of sensors.

36. The radiation delivery system of claim 35 wherein the beacon signal from each beacon is a unique signal different from the other beacon signals.

37. The radiation delivery system of claim 35 wherein each beacon signal has a frequency different from the frequencies of other beacon signals.

38. The radiation delivery system of claim 35 wherein the beacon signals has a signal strength, and the data processing unit calculates the spatial location of the beacons and target isocenter based upon the beacon signals.

39. The radiation delivery system of claim 34 wherein the reference device is mounted on the radiation delivery assembly and provides a reference signal measurable by the sensors.

40. The radiation delivery system of claim 34 wherein the reference device provides a signal measurable by the plurality of sensors, the data processing unit is coupleable to the linear accelerator reference device and the data processing unit is configured to identify the location of the machine isocenter relative to the plurality of sensors based upon the measurements of the reference signal.

41. The radiation delivery system of claim 34, further comprising an excitation source positionable exterior of the body and configured to excite the beacon to produce the beacon signal.

42. The radiation delivery system of claim 34 wherein the plurality of sensors defines a sensor array positionable as a unit relative to the beacon.

43. The radiation delivery system of claim 34, further comprising a patient support structure shaped and sized to support the body in which the beacon is implanted, and the sensors are mounted in a fixed location relative to a portion of the patient structure.

44. The radiation delivery system of claim 34 wherein the patient support structure has a base and a tabletop movably adjustable relative to the sensors for positioning the target isocenter co-incident with the machine isocenter.

45. The radiation delivery system of claim 34, further comprising a monitoring system having a feedback portion coupled to the data processing unit and

configured to provide feedback information about the position of the machine isocenter and the target isocenter relative to each other.

46. The radiation delivery system of claim 34 wherein the beacon is one of a plurality of beacons, the beacons each being axially misaligned with each other, and the computer controller being configured to calculate a three-dimensional spatial position and orientation of the target relative to the plurality of sensors.

47. The radiation delivery system of claim 34 wherein the radiation therapy delivery source includes a movable gantry, and the reference device is mounted on the gantry at a position spaced apart from the plurality of sensors.

48. The radiation delivery system of claim 34 wherein the reference device is a wireless excitable beacon mounted to the radiation therapy delivery source.

49. The radiation delivery system of claim 34 wherein the radiation therapy delivery assembly is one of an intensity modulated radiation therapy (IMRT) system, a three-dimensional conformal external beam radiation system, a stereotactic radiosurgery system, tomo therapy and a brachytherapy system.

50. The radiation delivery system of claim 34 wherein the data processing unit contains visual diagnostic data identifying the location of the beacon and the location and orientation of the target, the data processing unit being configured to compare the visual diagnostic data to the location and spatial orientation of the target within the body relative to the plurality of sensors and to identify a target isocenter within the target prior to application of radiation treatment to the target.

51. A radiation treatment system usable to deliver ionizing radiation to a selected target within a body, comprising:

a movable gantry configurable to deliver the ionizing radiation at a treatment isocenter remote from the gantry;

a beacon fixable at a position relative to the target within the body, the beacon being excitable by an external source to produce a measurable beacon signal while in the body;

sensors spaced apart in a known geometry relative to each other and positioned to measure the beacon signal, each sensor being configured to measure the beacon signal and provide a beacon measurement signal;

a linear accelerator reference device mounted on the gantry at a known position relative to the machine isocenter; and

a computer controller coupled to the sensors to receive the beacon measurement signals and configured to use the beacon measurement signals to determine the location of the target volume and a target isocenter in the target volume relative to the sensors, and the computer controller being coupled to the reference device and configured to identify the location of the target isocenter relative to the machine isocenter.

52. The radiation treatment system of claim 51, further comprising a patient support structure shaped and sized to support the body in which the beacon is implanted, and the sensors are mounted in a fixed location relative to a portion of the patient support structure.

53. The radiation treatment system of claim 51, further comprising a monitoring system coupled to the computer controller, the monitoring system having a feedback portion configured to provide feedback information about the position of the machine isocenter and the target isocenter relative to each other.

54. The radiation treatment system of claim 43 wherein the computer controller and monitoring system are configured to identify and display real time movement of the target and machine isocenters relative to each other.

55. The radiation treatment system of claim 53, wherein the computer controller contains imaging data identifying the location of the beacon and the location and orientation of the target, the computer controller being configured to compare the imaging data to the location and spatial orientation of the target within the body relative to the

plurality of sensors and to identify a target isocenter within the target prior to application of radiation treatment to the target.

56. A radiation target alignment system usable with a radiation delivery source that delivers selected doses of radiation to a selected target in a body, comprising:

an imaging system configured to obtain image data of the target and at least one beacon positioned within the body, and to define a simulated target model having a spatial relationship and orientation within the body using the image data;

a beacon implantable in or on the body at a selected position relative to the target, the beacon being excitable by an external source to produce a measurable signal while in the body;

a plurality of sensors spaced apart in a known geometry relative to each other and positioned to identify the signal from the beacon in the body, each sensor being configured to measure the beacon signal and provide a beacon measurement signal;

a data processing unit coupled to the sensors to receive the beacon measurement signal for the beacon, the data processing unit being configured to use the beacon measurement signal and the image data to determine an actual target model of the target's actual location within the body relative to the plurality of sensors, and to identify a target isocenter within the target, the data processing unit being configured to compare and align the actual target model and the simulated target model in preparation for radiation treatment of the target.

57. The radiation target alignment system of claim 56 wherein in the beacon is one of a plurality of beacons attachable to the body, and each beacon generate a unique measurable signal different from the other beacon signals.

58. The radiation target alignment system of claim 57 wherein the plurality of beacons includes at least three beacons.

59. The radiation target alignment system of claim 57 wherein the plurality of beacons each axially misaligned with each other.

60. The target locating and tracking system of claim 56 wherein the beacon is one of a plurality of beacons, and the beacons each being axially misaligned with each other, the data processing unit being configured to identify a three-dimensional spatial position as well as orientation of the target relative to the plurality of sensors.

61. The radiation target alignment system of claim 56 with the radiation delivery source adapted to deliver radiation to a machine isocenter spaced apart from the radiation delivery source, wherein the data processing unit is configured to identify the location of the machine isocenter relative to the actual target isocenter.

62. The radiation target alignment system of claim 56, further comprising a monitoring system coupled to the data processing unit, the monitoring system having a display portion configured to display the position of the machine isocenter and the actual target isocenter relative to each other.

63. The radiation target alignment system of claim 62 wherein the data processing unit and monitoring system are configured to identify and display real time movement of the target and machine isocenters relative to each other.

64. An adjustable patient support assembly for use with a radiation delivery system that delivers radiation to a selected target in a body, the radiation being delivered to a machine isocenter spaced apart from the radiation delivery source, comprising:

a base;

a support structure attached to the base;

sensors spaced apart from each other in a known geometry relative to each other and coupled to the base, the sensors being positioned to measure a signal from an excitable beacon implantable in the body at a selected position relative to the target, each sensor being configured to provide signal measurement data;

a data processing unit coupled to the sensors to receive the signal measurement data for the beacon, the data processing unit being configured to use the signal measurement data for the beacon to determine the location of the target and a target isocenter in the target

relative to the sensors, the data processing unit being configured to identify the location of the target isocenter relative to the machine isocenter; and

a movement control device connected to the support structure to selectively move the support structure relative to the base and the sensors, the movement control device coupled to the data processing unit and being movable in response to the information from the data processing unit to position the target isocenter co-incident with the machine isocenter.

65. A method of identifying and tracking a selected target in a body for application of radiation to the target from a radiation delivery source, comprising:

determining a general location of the target in the body;

implanting a beacon in the body at a selected position relative to the target, the beacon being excitable by an external excitation source to produce an identifiable beacon signal while in the body;

exciting the implanted beacon with the external excitation source to produce the identifiable beacon signal;

measuring the beacon signal from the implanted beacon with sensors exterior of the body, the sensors being positioned at a known geometry relative to each other;

determining a target isocenter in the target within the body based upon the measurements from the sensors of the beacon signal;

determining a position of a reference device relative to the plurality of sensors, the reference device being located at a known geometry relative to the radiation delivery device;

determining the location of a machine isocenter relative to the plurality of sensors based upon the position of the reference device;

positioning the body relative to the radiation delivery device with the target isocenter being coincident with the machine isocenter; and

applying radiation from the radiation delivery device to the machine isocenter and the target at the target isocenter.

66. The method of claim the 65, further comprising:

implanting a plurality of beacons in the body at a selected positions and orientations relative to the target, each beacon being excitable by the external excitation source to produce an identifiable beacon signal unique to the respective beacon; exciting the implanted beacons with the external excitation source to produce the identifiable unique beacon signals;

measuring the beacon signals from each of the implanted beacons with the sensors exterior of the body;

determining a location of the target isocenter in the target within the body based upon the measurements from the sensors of the beacon signals.

67. The method of claim 65, further comprising determining the location and orientation of the target in the body relative to the sensors.

68. The method of claim 65 wherein the beacon generates the beacon signal having a signal strength and measuring the beacon signals includes measuring the beacon strength with each sensor.

69. The method of claim 65, further comprising providing a monitoring system coupled to a computer controller and providing feedback from the computer controller to the monitoring system about the position of the machine isocenter and the target isocenter relative to each other.

70. The method of claim 69 wherein the monitoring system includes a visual display portion, and providing feedback includes providing a visual representation on the visual display portion of the positions of the target and machine isocenters relative to each other.

71. The method of claim 65, further comprising implanting at least three beacons in the body at selected positions relative to the target, each of the at least three beacons being axially misaligned with each other.

72. The method of claim 65 further comprising positioning the body at a selected location generally adjacent to the radiation delivery source, and wherein measuring the beacon signal, determining a location of the target isocenter, determining the location of a machine isocenter, and positioning the body relative to the radiation delivery device so the target isocenter being coincident with the machine isocenter are performed in real time prior while the body is positioned at the selected location generally adjacent to the radiation delivery device.

73. The method of claim 65 wherein the target is a tumor, and implanting the beacon includes implanting the beacon in or immediately adjacent to the tumor, and determining the location of the target isocenter includes determining a location of the target isocenter in the tumor.

74. The method of claim 65 wherein the sensors are mounted to a movable support table that supports the body generally adjacent to the radiation delivery device, and positioning the body includes moving a portion of the support table relative to the radiation delivery device and to the sensors to align the target isocenter with the machine isocenter.

75. The method of claim 65, further comprising monitoring the position of the target isocenter relative to the machine isocenter in real time during irradiation of the target, and interrupting the irradiation of the target if the target isocenter moves out of alignment with the machine isocenter.

76. A method of delivering radiation therapy on a selected target within a body, comprising:

implanting a beacon in the body at a selected position relative to the target, exciting the implanted beacon with an excitation source external of the body to produce an identifiable beacon signal;

measuring the beacon signal from the implanted beacon with sensors positioned exterior of the body and at a known geometry relative to each other;

determining a target isocenter in the target within the body based upon the measurements from the sensors of the beacon signal;

determining the location of a machine isocenter of a radiation delivery assembly relative to the plurality of sensors based upon the position of the reference device and relative to the target isocenter;

positioning the body relative to the radiation delivery device so the target isocenter is co-incident with the machine isocenter;

applying radiation from the radiation delivery device to target at the target isocenter and the machine isocenter; and

monitoring in real-time the actual position of the target isocenter relative to the machine isocenter during application of the radiation to the target.

77. A radiation treatment planning method for establishing a therapeutic procedure for delivering ionizing radiation to a selected target, comprising:

obtaining imaging data a selected target within a body;

implanting an excitable beacon in the body at a selected location relative to the target;

exciting the implanted beacon with the external excitation source to produce the identifiable beacon signal from the beacon while in the body;

measuring the beacon signal from the implanted beacon with a plurality of sensors exterior of the body, the sensors being positioned at a known geometry relative to each other;

determining a shape, and spatial orientation of the target within the body from the imaging data;

determining a target isocenter in the target within the body based upon the measurements from the sensors of the beacon signal; and

developing a radiation dosage and delivery protocol for irradiating the target at the target isocenter based upon the shape and spatial orientation of the target.

78. The method of claim 77, further comprising:

positioning the body with the target and implanted beacon therein at a selected position relative to a radiation delivery assembly, the radiation delivery assembly being configured to selectively deliver focused radiation to a target isocenter spaced apart from the radiation delivery assembly;

determining the location of a machine isocenter relative to the plurality of sensors;

positioning the body relative to the radiation delivery device with the target isocenter being substantially co-incident with the machine isocenter; and

delivering the radiation from the radiation delivery assembly to the machine isocenter and to the target at the target isocenter.

79. The method of claim 77, further comprising defining a three-dimensional simulated target model with a selected position and orientation relative to the body based upon the imaging data; and defining an three-dimensional actual target based upon the measurements of the beacon signals, providing a feedback device that provides feed back information about the location and orientation of the simulated target model and the actual target model, and moving the body to align orientation of the target and actual models prior to the delivery of the radiation to the target.

80. A method of positioning a body relative to a radiation delivery device for delivery of radiation to a target within the body, comprising:

positioning the body on a movable support assembly

exciting an excitable beacon with an excitation source exterior of the body, the beacon being implanted within the body at a selected position relative to the target, the excited beacon providing an identifiable beacon signal;

measuring the beacon signal from the implanted beacon with a plurality of sensors exterior of the body, the plurality of sensors being positioned at a known geometry relative to each other and relative to the support assembly;

determining a target isocenter in the target within the body based upon the measurements from the sensors of the beacon signal;

determining the location of a machine isocenter relative to the plurality of sensors based upon the position of the radiation delivery assembly;

comparing the location of the target isocenter with the location of the machine isocenter; and

moving a portion of the support

portion and the body together relative to the machine isocenter to position the target isocenter co-incident with the machine isocenter.

81. The method of claim 80, wherein the plurality of sensors being connected to the support assembly, and moving the portion of the support portion includes moving the portion of the support portion and the body together relative to the plurality of sensors.

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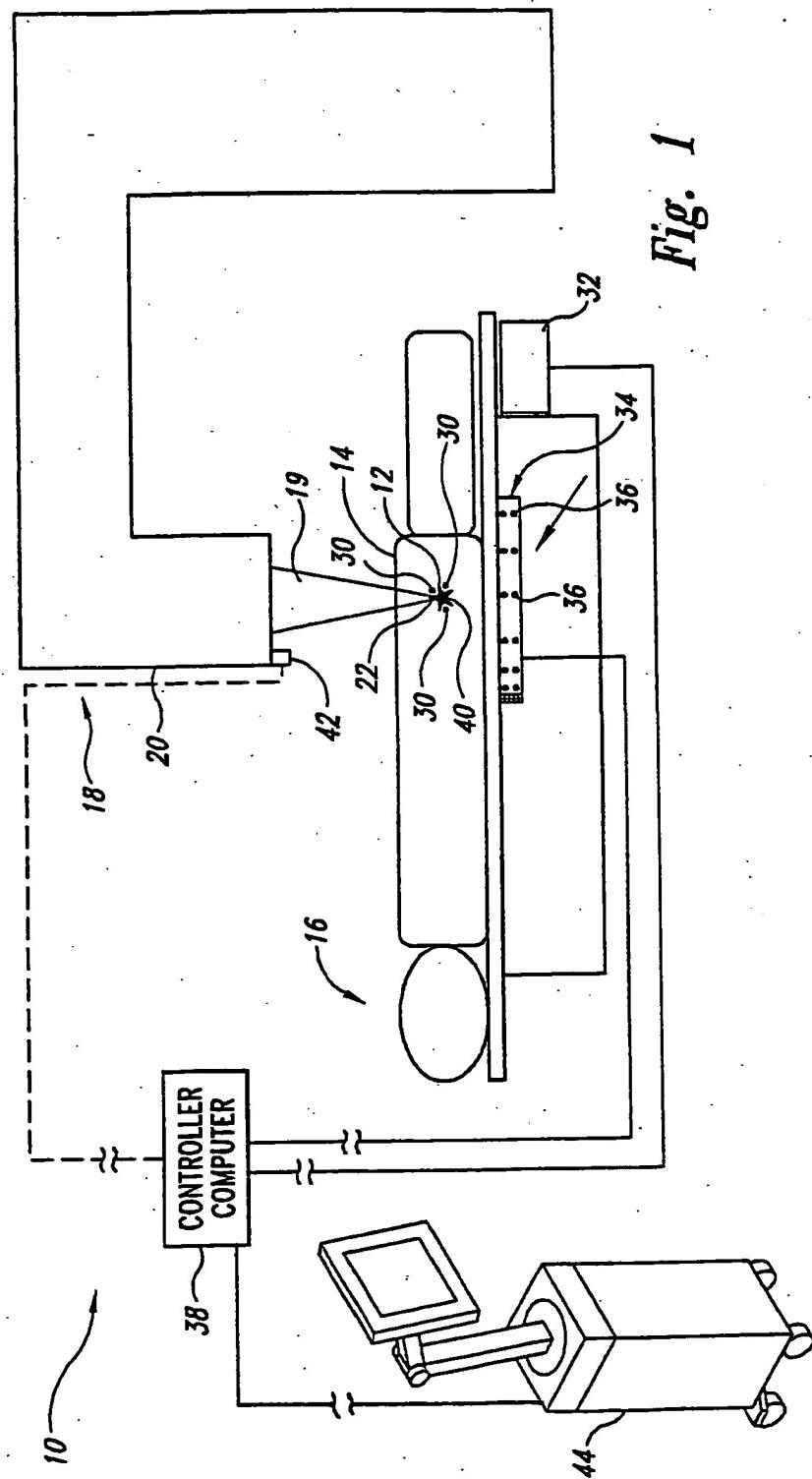


Fig. 1

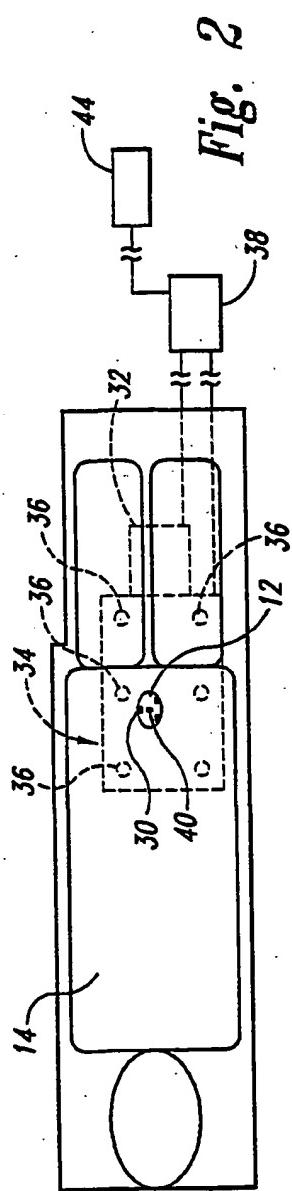


Fig. 2

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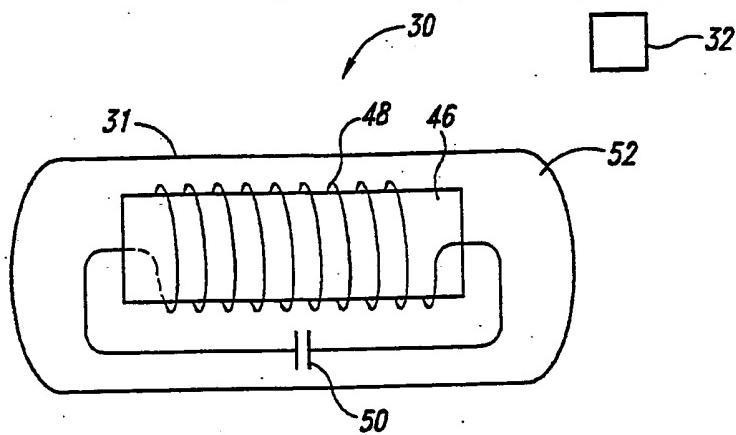


Fig. 3

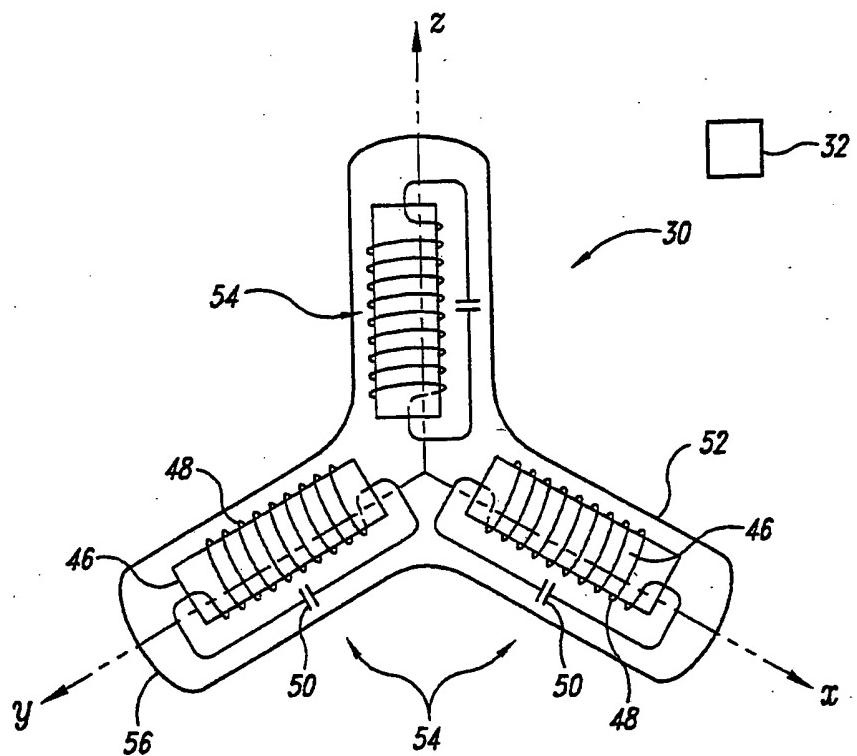
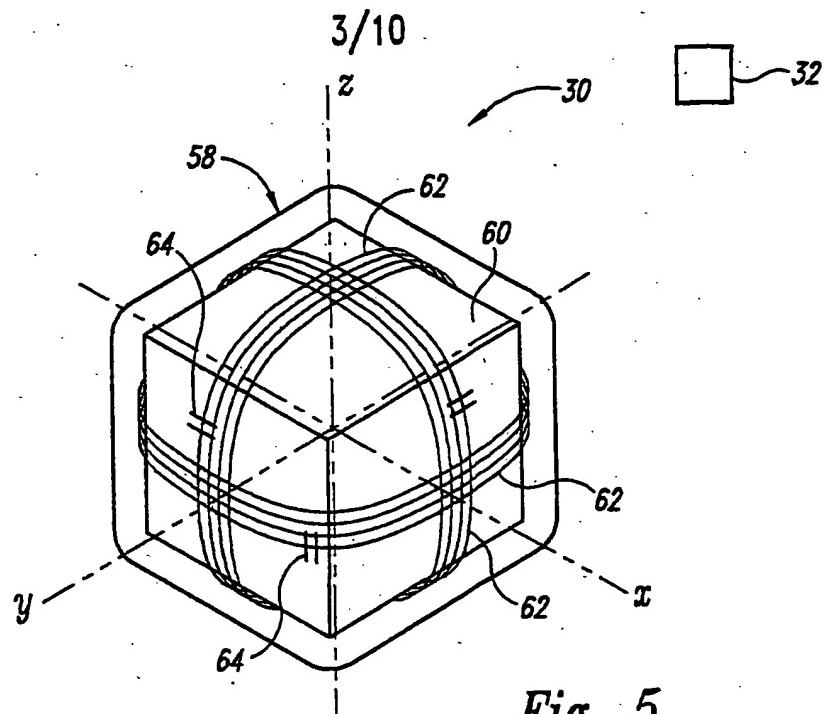
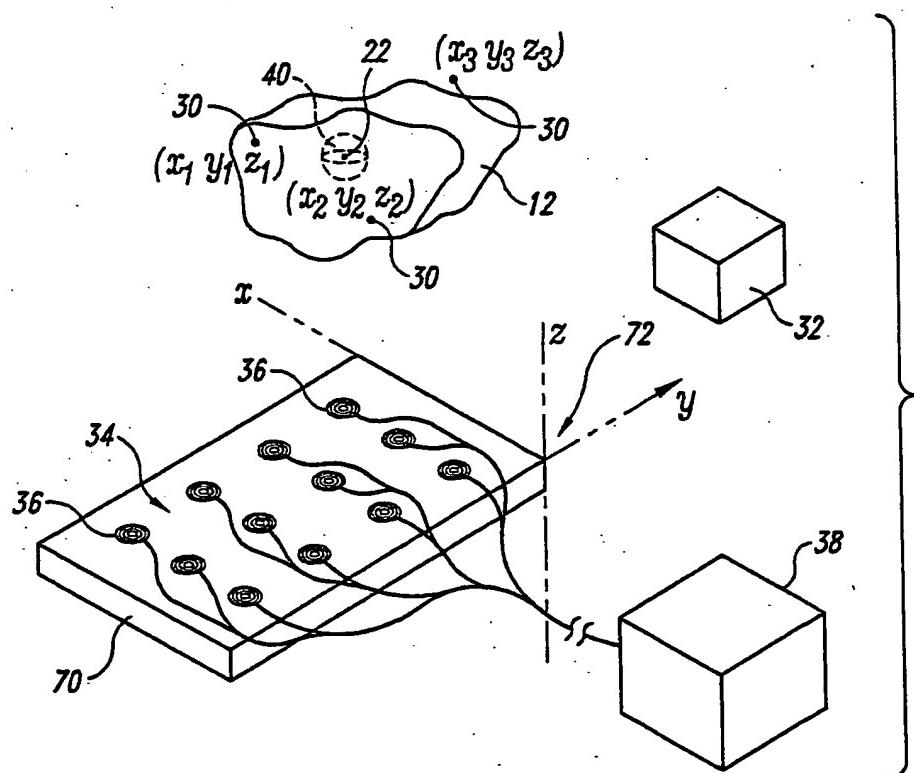


Fig. 4



*Fig. 5*



*Fig. 6*

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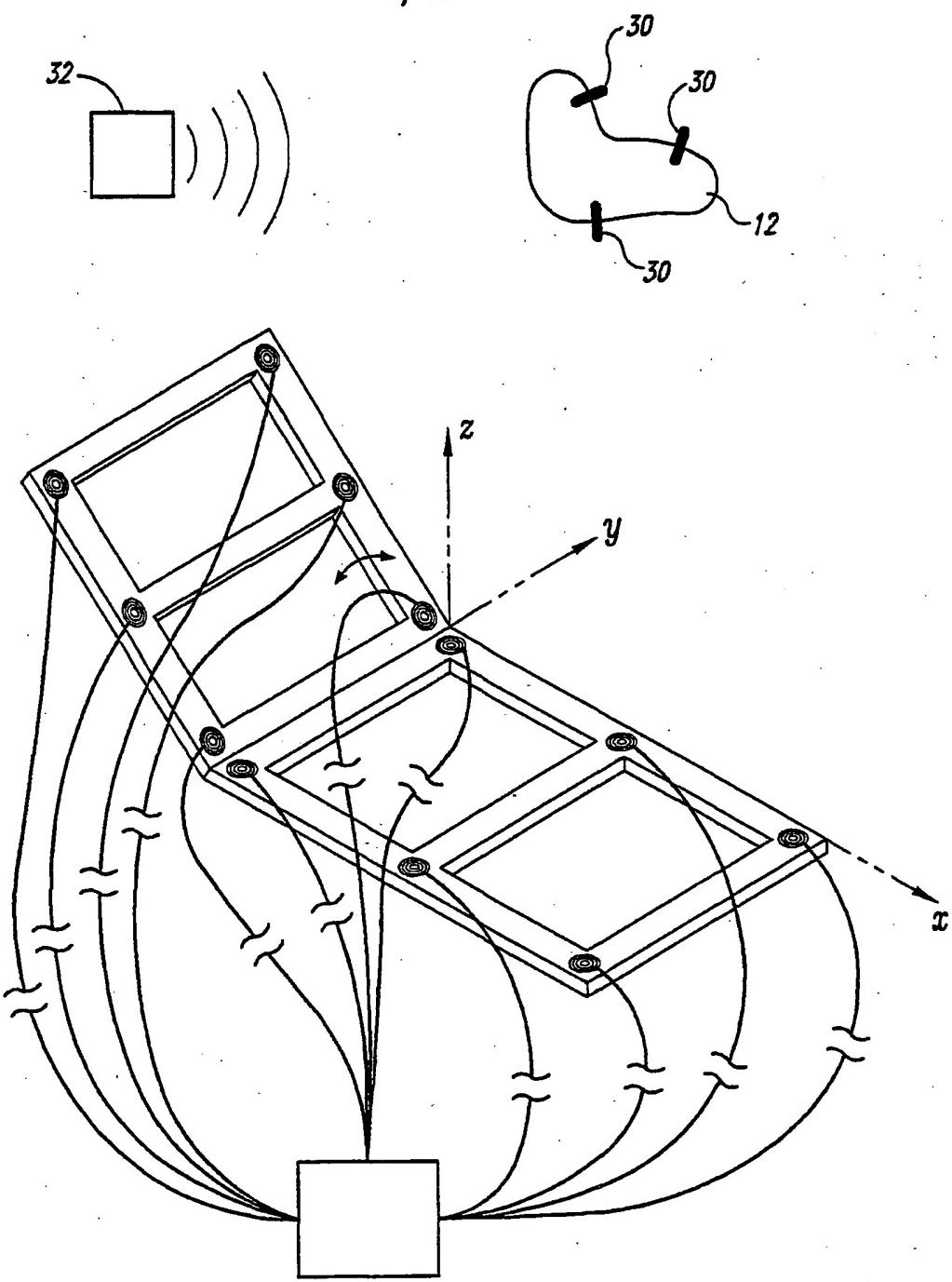


Fig. 7

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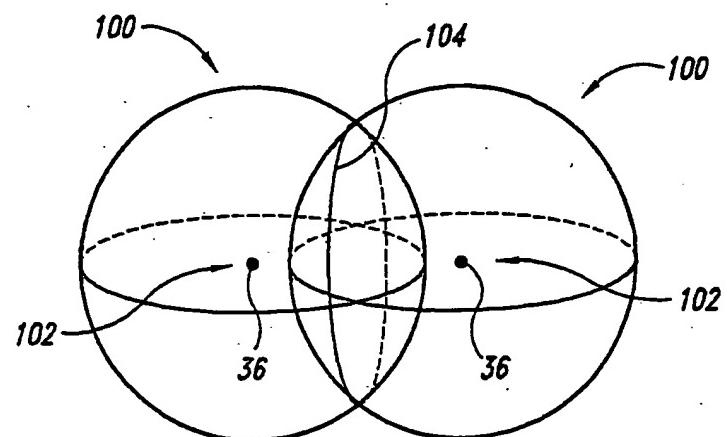


Fig. 8

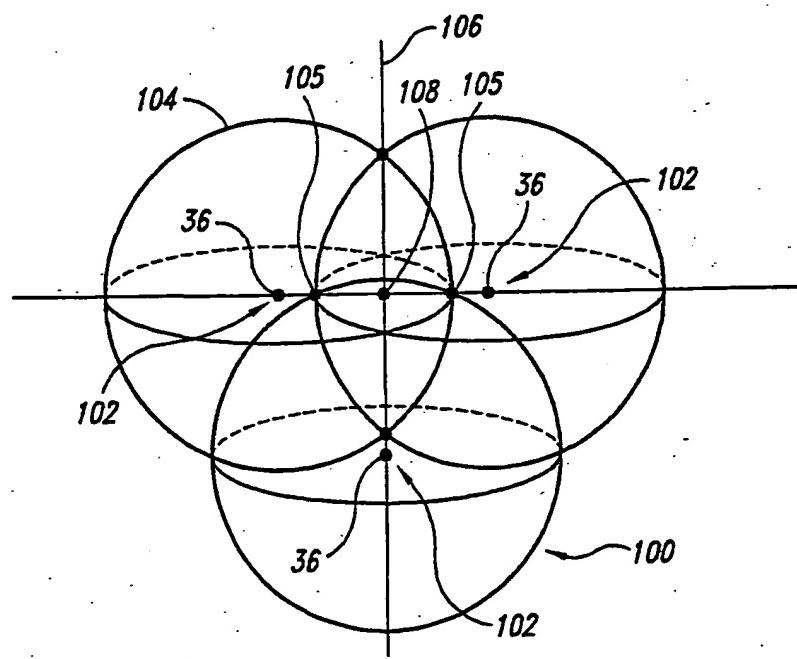


Fig. 9

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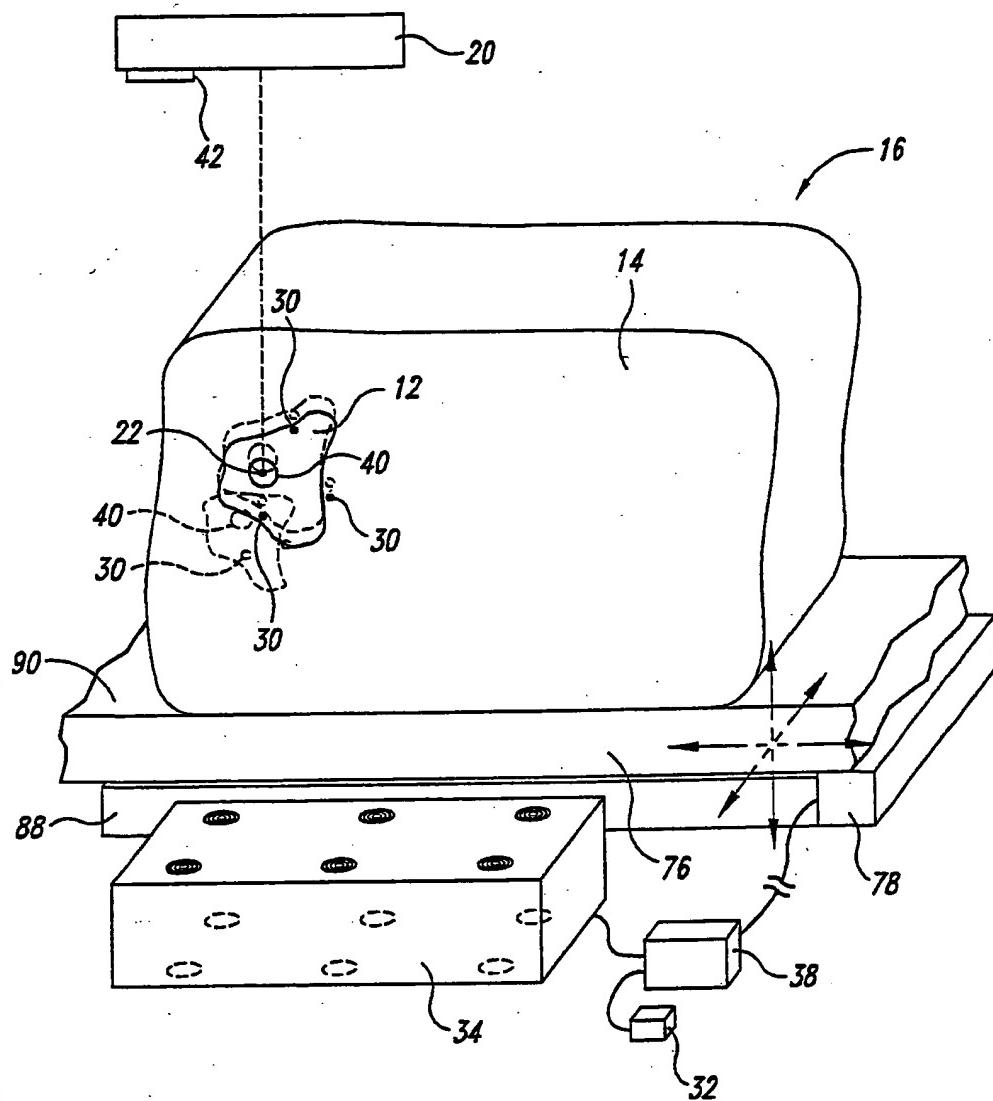


Fig. 10

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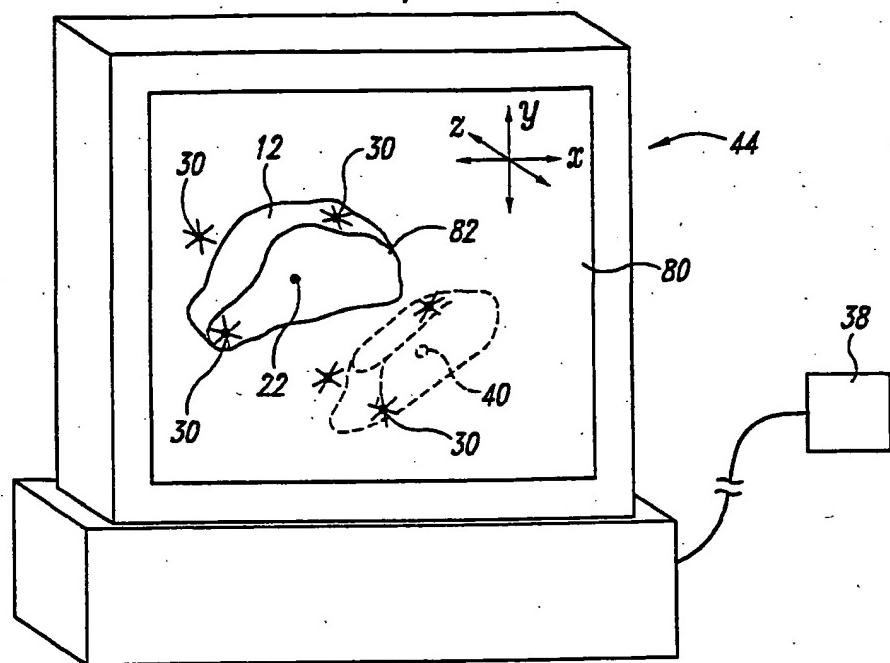


Fig. 11

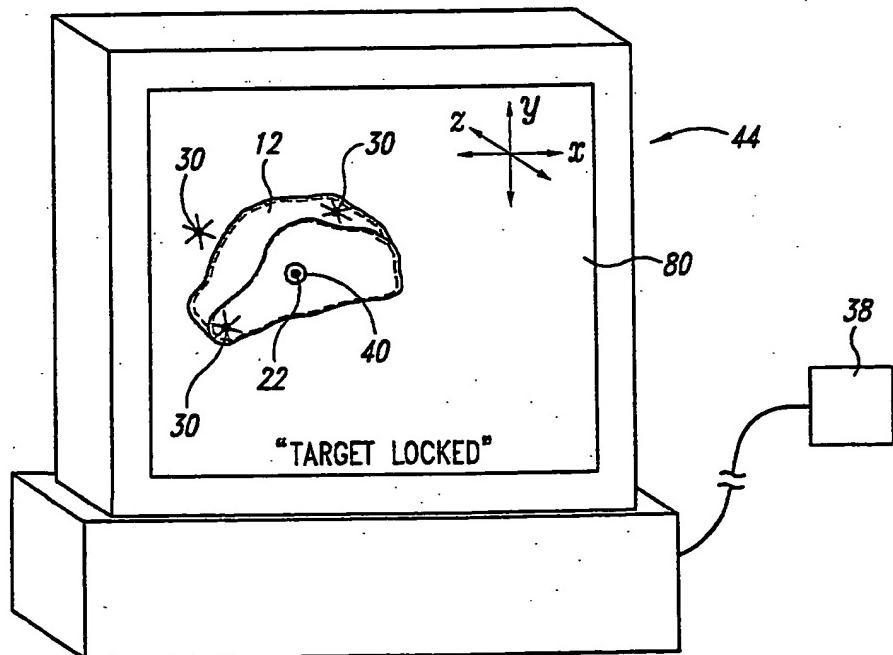


Fig. 12

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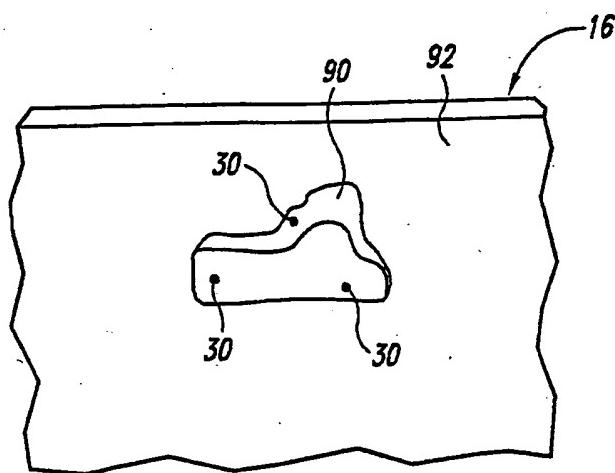


Fig. 13

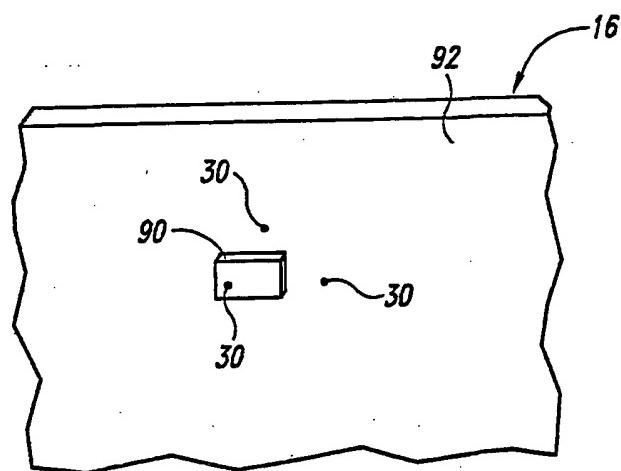


Fig. 14

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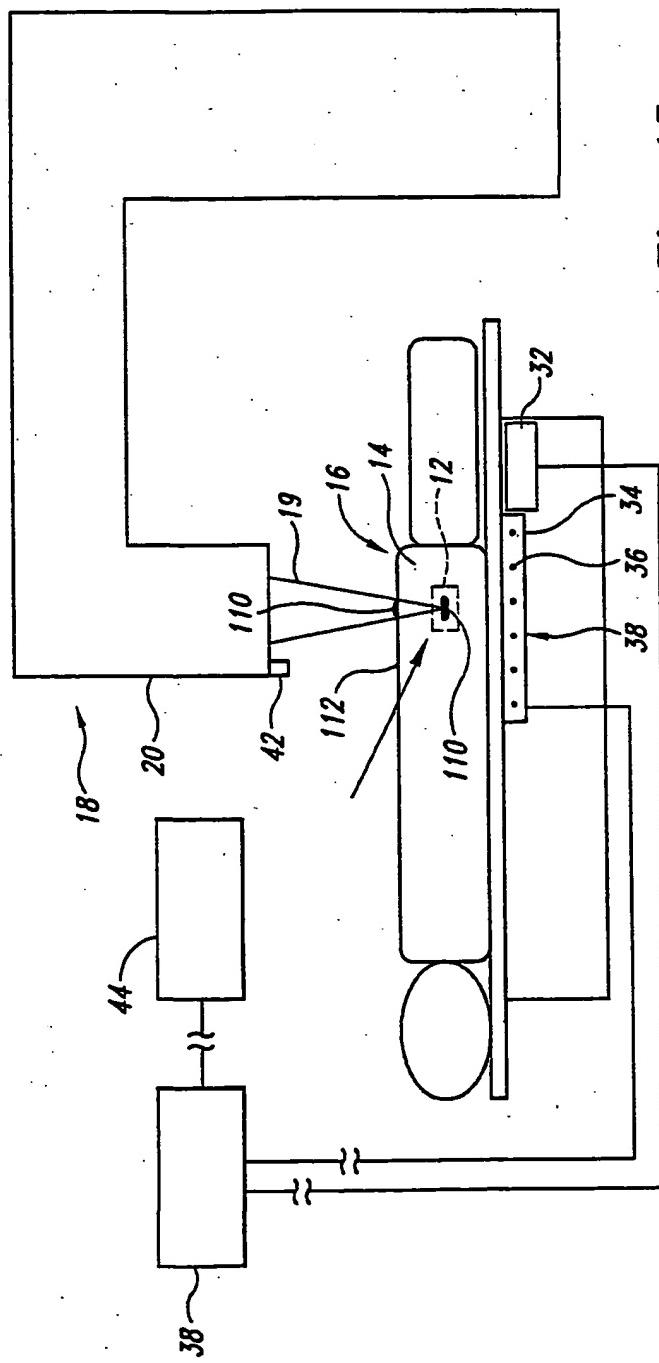


Fig. 15

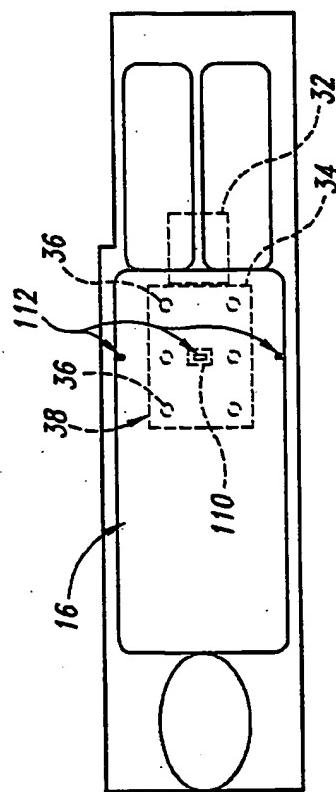


Fig. 16

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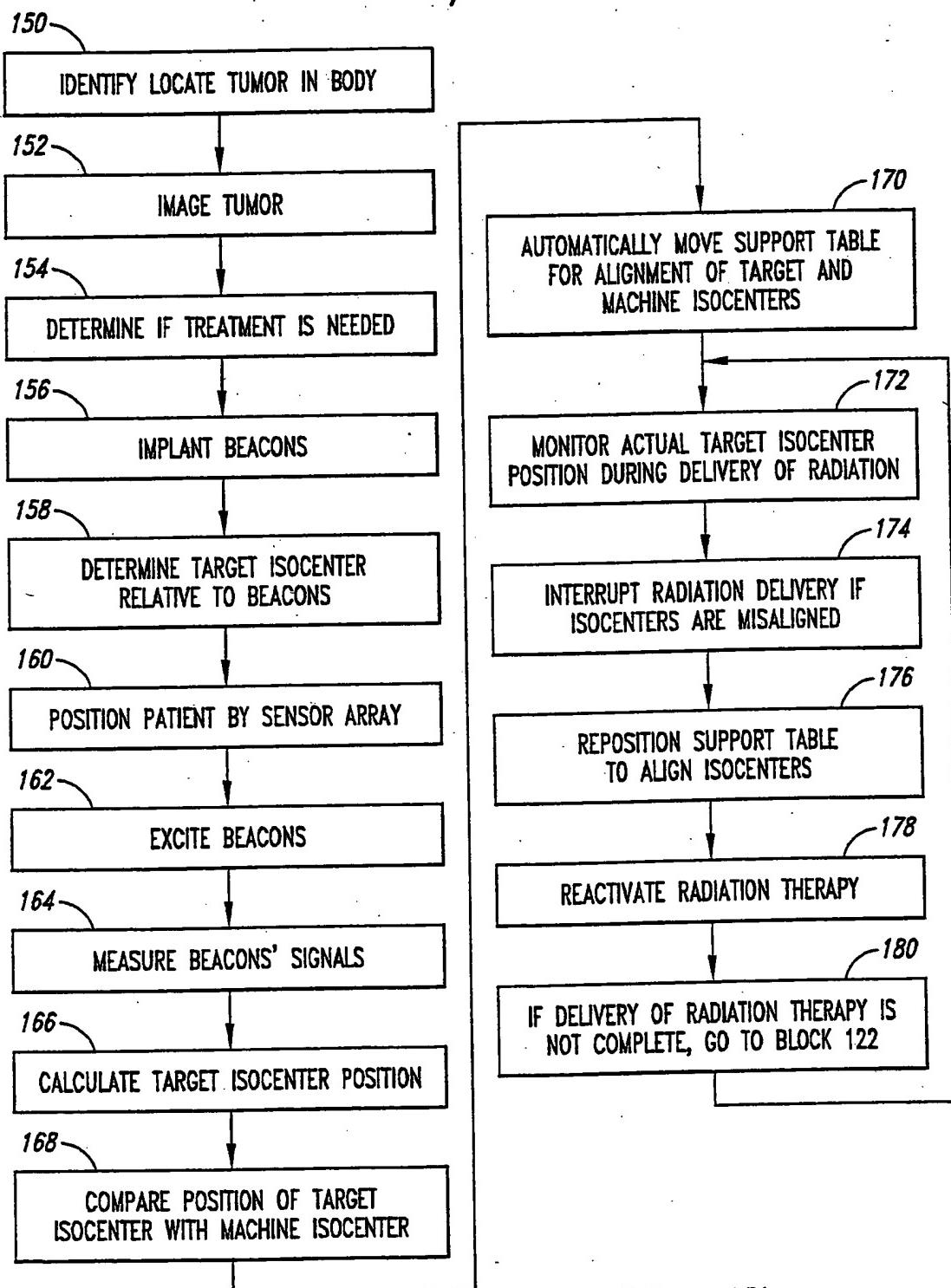


Fig. 17

## INTERNATIONAL SEARCH REPORT

International Application No

PCT/US 02/17876

A. CLASSIFICATION OF SUBJECT MATTER  
IPC 7 A61N5/10

According to International Patent Classification (IPC) or to both national classification and IPC

## B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC 7 A61N A61B

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practical, search terms used)

EPO-Internal

## C. DOCUMENTS CONSIDERED TO BE RELEVANT

| Category * | Citation of document, with indication, where appropriate, of the relevant passages                                       | Relevant to claim No. |
|------------|--|-----------------------|
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|            |  | -/-                   |



Further documents are listed in the continuation of box C.



Patent family members are listed in annex.

## \* Special categories of cited documents :

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\*T\* later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention

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Date of the actual completion of the international search

1 October 2002

Date of mailing of the international search report

08/10/2002

Name and mailing address of the ISA

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## INTERNATIONAL SEARCH REPORT

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## C(Continuation) DOCUMENTS CONSIDERED TO BE RELEVANT

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| A        | US 6 239 724 B1 (PORAT YARIV ET AL)<br>29 May 2001 (2001-05-29)<br>column 8, line 42 -column 13, line 18 | 1,23,34,<br>51,56,64  |
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## INTERNATIONAL SEARCH REPORT

International application No.  
PCT/US 02/17876

### Box I Observations where certain claims were found unsearchable (Continuation of Item 1 of first sheet)

This International Search Report has not been established in respect of certain claims under Article 17(2)(a) for the following reasons:

1.  Claims Nos.: 65-81 because they relate to subject matter not required to be searched by this Authority, namely:  
Rule 39.1(1v) PCT - Method for treatment of the human or animal body by surgery and/or therapy
2.  Claims Nos.: because they relate to parts of the International Application that do not comply with the prescribed requirements to such an extent that no meaningful International Search can be carried out, specifically:
3.  Claims Nos.: because they are dependent claims and are not drafted in accordance with the second and third sentences of Rule 6.4(a).

### Box II Observations where unity of invention is lacking (Continuation of Item 2 of first sheet)

This International Searching Authority found multiple inventions in this International application, as follows:

1.  As all required additional search fees were timely paid by the applicant, this International Search Report covers all searchable claims.
2.  As all searchable claims could be searched without effort justifying an additional fee, this Authority did not invite payment of any additional fee.
3.  As only some of the required additional search fees were timely paid by the applicant, this International Search Report covers only those claims for which fees were paid, specifically claims Nos.:
4.  No required additional search fees were timely paid by the applicant. Consequently, this International Search Report is restricted to the invention first mentioned in the claims; it is covered by claims Nos.:

#### Remark on Protest

- The additional search fees were accompanied by the applicant's protest  
 No protest accompanied the payment of additional search fees.

**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International Application No

PCT/US 02/17876

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**INTERNATIONAL SEARCH REPORT**  
Information on patent family members

International Application No

PCT/US 02/17876

| Patent document cited in search report | Publication date | Patent family member(s) |           | Publication date |
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